GRAVITY AND MAGNETIC SURVEYS IN SUPPORT OF GEOTHERMAL EXPLORATION ON MAUI, HAWAII

BY

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SUMMARY

PART I. GEOLOGIC AND GEOPHYSICAL BACKGROUND

INTRODUCTION

Detailed gravity and magnetic land surveys were conducted on the island of Maui during the summer of 1980. This report summarizes the work in three sections: Part I summarizes the purpose of the study, its scope and the geology of the area. Part II describes the field methods used and the reduction of data to map and cross-section form; Part III summarizes the data analysis to date.

Four separate areas were mapped: Lahaina-Olowalu, Paia-Haiku, Hana and Makena (Fig. 1).

PURPOSE AND SCOPE

The gravity and magnetic surveys presented in this report are part of an ongoing assesment of geothermal resources for the major islands in the Hawaiian chain (Thomas and others, 1979). It is hoped that the data will contribute to the overall knowledge of the geology of the island, but, in particular, it was hoped that detailed information would be obtained about the location and character of intrusive bodies and dike zones.

GEOLOGY

Maui is the second youngest island in the Hawaiian chain. It is made up of two volcanic systems: West Maui and Haleakala (Fig. 1). Two dike systems are known to radiate from the central caldera of West Maui, but the rift zones are not well defined. Haleakala (East Maui) structure is characterized by a major southwest-east rift zone with one minor zone trending northeast from the summit. For the purposes of this report the three rift zones on East Maui are labeled as the East, Southwest and Northwest Rifts. There are no known surface zones of thermal activity along these rifts, but thermal reservoirs may exist at depth. The last volcanic activity was in 1790 along the southwest rift zone.

PREVIOUS GEOPHYSICAL STUDIES

Aeromagnetic surveys were reviewed by Malahoff and Woollard (1965). They interpreted a total force magnetic map (Fig. 2) in terms of broad, deep structure. Although such regional analyses are not of prime interest in this report, the analyses in Part III will include a summary of Malahoff and Woollard's interpretation.

A comprehensive statewide gravity survey was made in 1965 by Kinoshita and Okamura and presented as a Bouguer map (solid contours on Fig. 3). They used a Bouguer reducing density of 2.3 gm/cc. Topographic corrections were made at 15% of the stations and estimated at the remaining stations, probably by linear extrapolation. The authors consider the Bouguer values at most stations to be accurate within 3 milligals. Woollard (1965) tabulated all available gravity data for Maui and his unpublished gravity contours are included on Figure 3.

A recent resistivity study (Mattice,1981) estimated the depth and electrical properties of the seawater-saturated basalt in an effort to estimate temperatures at depth. The lowest resistivity values observed were in the Olowalu area (Ukumehame Canyon), indicating temperatures of 62 to 171 C at depths greater than 200 meters.

PART II. FIELD METHODS AND DATA REDUCTION

GRAVITY SURVEY

FIELD METHODS.- Two Worden gravimeters were used in the present survey. These were calibrated by occupying selected gravity stations established by a previous high-precision survey (Schenck and Laurila,1978). Approximately half of the stations were located at those locations where "spot" elevations were given on USGS quadrangle maps (1:24000) or where bench marks were available. Because spot elevations are considered accurate to 0.1 of the contour interval (usually 40 feet), elevations are considered accurate to 5 feet, or approximately 0.5 milligal. Approximately half of the stations were not at spot elevations and those elevations are estimated to be accurate only to 10 feet at best. Hence, the overall Bouguer maps cannot be considered reliable for anomalies less than 1 milligal in amplitude. Areas of special interest observed in the current survey may need to be surveyed in detail at closer intervals with elevation sontrol.

BOUGUER DENSITY.- Terrain and Bouguer corrections require knowledge of rock densities in the near surface. Strange and others (1965) summarized the available densities of rocks on the Hawaiian islands as 2.3 gm/cc for the dry density above sea level and 2.55 gm/cc for the wet density below sea level. Kinoshita and Okamura (1965) also used 2.3 gm/cc for a Bouguer density. In a later study, Wollard (1965) assumed 2.35 gm/cc as the most probable density for the mass above sea level.

The above studies were the basis for using a Bouguer density of 2.35 gm/cc for data reduction in this study. Nettleton (1939) has noted that the appropriate Bouguer density is the one at which the gravity anomaly least resembles the elevation contours. As a test, bouguer gravity maps were constructed for the Paia-Haiku area using various densities from 2.35 to 3.0 gm/cc, and then compared with the elevation contours. The comparisons were not conclusive, but the map based on a Bouguer density of 2.34 gm/cc (Fig. 4) shows many of the contours along the coastal area at right angles to the elevation contours (Fig. 1), meeting Nettleton's criterion of least resemblance. As expected, the Bouguer contours have regional similarities to the elevation contours, especially toward the Haleakala summit (see also Fig. 3).

DATA REDUCTION.- All gravity and magnetic data gathered in this survey are on magnetic tape and on permanent file with the Geothermal Section of the Hawaii Institute of Geophysics. Data reduction for this study was entirely by computer using an algorithm by Kwon and Rudman (1977). Table 1 illustrates the form of the input data on file. Output options from the program include listings of the data after it has been corrected for tide, latitude, drift, free air, and Bouguer (with densities selected by the user). A map output of any or all of the above options is easily obtained.

TERRAIN CORRECTIONS.- A comparison of terrain corrected Bouguer contours (Kinoshita and Okamura, 1965) with uncorrected contours (Woollard, 1965) shows no essential differences in the areas of interest in this survey (Fig. 3). The Paia-Haiku and Lahaina-Olowalu areas, with adequate control, display identical contours. The Hana area has so few stations that the comparison is not meaningful. The Makena area, with somewhat more control, displays such a gentle gradient that the differences observed would not change the local anomalies by more than a milligal. One milligal is the limit of accuracy anticipated for the given elevation control. Hence, terrain corrections were not applied.

CONTOURING OF DATA.- Most of the data presented in this report were contoured by hand. For comparative purposes, the data were also routinely contoured by computer using a standard CDC program available at Indiana University. Computer-contouring involves generating a uniformly spaced grid of interpolated values based on an average of the six nearest points weighted by distance. Contours based on such averaging do not honor individual points as strongly as one might in the hand-contouring process. For local studies this author believes that computer-contoured maps are not always adequate.

PAIA-HAIKU AREA.- Two hundred and sixty gravity readings were made in the Pai-Haiku area, including repeated visits to base stations at two-to-three hour intervals. Of these readings, one hundred and forty-eight stations were used to construct a Bouguer gravity map with a one-milligal contour interval (Fig. 4). The reduced data were normalized to match an arbitrarily selected gravity value obtained from the statewide survey of Woollard (Fig. 3).

Comparison of the statewide map with this survey's map shows a close correlation of the regional trends.

LAHAINA-OLOWALU AREA.- Two hundred and thirty-one gravity readings were obtained in the Lahaina-Olowalu area. Of these, one hundred and fifty- five stations were used to construct the Bouguer maps (shown here as two separate maps, Figs. 5 and 6). Again, the values were normalized to match an arbitrarily selected value from Woollard's statewide map. The contour interval on the statewide maps (10 milligals) is too large to permit meaningfuyl of the two maps. It is clear, however, that much more detail is available with the current maps.

MAKENA AREA.- Ninety-six gravity readings were made in the Makena area. Sixty-nine stations were selected to prepare a hand-contoured Bouguer map (Fig. 7). Values were normalized to the statewide map. The station density in Makena is less than the previous areas.

HANA AREA.- Forty gravity readings were obtained in the Hana area. Only twenty nine were used to obtain a Bouguer map (Fig. 8). Most of the stations were located along coastal roads; such restricted data is difficult to contour and the data must be used with discretion during the analysis. Machine-contouring is not meaningful with so few points.

MAGNETIC SURVEYS

FIELD TECHNIQUES.- A Uni-Mag portable proton was used to obtain total field measurements with approximately 10 gamma resolution. A second instrument was installed at a fixed base station to monitor magnetic storms on a Rustrac recorder. No storms were observed during the field measurements; observed fluctuations seldom exceeded twenty gammas.

Two types of magnetic surveys were conducted: individual readings taken at each gravity station and continuous profiles at close intervals. The individual readings were not considered entirely reliable. Readings made within a few feet of a given station would sometimes show a gradient of 200 gammas within 50 feet. Typical reasons for such fluctuations are noise from AC power lines, high magnetic gradients from surface rocks, hidden iron objects, fence lines and instrument difficulties.

Several techniques were tried to solve the fluctuation problem. The sensor was mounted on an eight-foot staff to reduce surface magnetic effects. In addition, repeated measurements were made at each station; the average value being recorded as optimum. Despite these efforts, maps constructed on the basis of the individual station readings were not considered reliable enough to present in this report, although they are on file with the Geothermal Section.

Magnetic profiles were obtained at approximately 50 to 100 foot intervals in areas of special interest. It was felt that such profiles would permit easy identification of the noise as an oscillation superposed on an overall trend. It is usually an easy task to remove the oscillations through data enhancement techniques such as filtering, upward continuation, weighted averages and/or least squares fitting of trend lines.

MAGNETIC PROFILES.- Magnetic profiles were obtained in each of the mapping areas. Profile locations are given on the gravity maps (Figs. 4-8) and the profiles are plotted on Figures 9-12. Numerous short profiles several hundred feet in length were run to study the local gradient (although these profiles are not included in this report). Because a change of several hundred gammas in 100 feet was not uncmmon, only long wavelength anomalies of high amplitude were considered geologicall significant (e.g., anomalies greater than 1000 feet in length with amplitudes larger than 500 gammas).

PART III. GRAVITY AND MAGNETIC ANALYSIS

REGIONAL

Malahoff and Woollard's 1965 study of the aeromagnetic field over Maui (Fig. 2) is qualitatively summarized by superposing the outline of the primary centers of volcanism on the aeromagnetic contours (letters A-D). The elongate zones are Malahoff and Woollards's interpretation of the location of the rift zones. The isthmus between East and West Maui are seen as magnetically quiet. Table 2 summarizes Malahoff and Woollard's quantitative studies in terms of depth and shape of the magnetic sources. The volcanic centers on West Maui are seen as shallow features; East Maui structures are considered to be deeper intrusive bodies with essentially vertical orientation.

Comparison of the aeromagnetic data with the regional gravity contours of Kinoshita and Okamura (Fig. 2) show that the volcanic centers are associated with a significant positive Bouguer anomaly, indicating the presence of a dense, magnetic source rock for the volcanic core. The associated rift and dike systems (Figs. 1 and 2) manifest themselves as mild flexures of the gravity contours (Fig. 3).

LOCAL ANOMALIES

PAIA-HAIKU.- The Bouguer map of the Paia-Haiku area (Fig. 4) displays a portion of large positive anomaly observed on the statewide map (discussed above). In addition, the western part of the map shows a broad negative feature that is associated with the shallow alluvial deposits on the isthmus (Fig. 13).

The regional gravity of the area is also well displayed in profile on Figure 14; the statewide aeromagnetic data is included on the profile for comparison. Assuming a linear regional gravity gradient, the maximum anomaly observed along the gravity profile is less than one-milligal (the limit of accuracy of this survey). Despite this limitation, there is one area of interest; a minor anomaly is observed to occur at approximately the same location on both gravity and aeromagnetic profiles (see arrows on Fig. 13). These anomalies are also approximately coincident on the maps, occuring as linear features with a north-south trend (shaded areas on Figs. 2 and 4). Note that the trend is interrupted and, perhaps, offset to the east. The gravity contours are somewhat anomolous along an east-west line and the possibility of a fault is speculatively suggested.

The source of this linear feature, and its offset, may be the Northwest Rift zone sougth in this exploration program. Based on surface geologic evidence, the rift was originally projected as a northwest-southeast zone; Figure 15 shows the relative positions of the Nortwest Rift based on geology, gravity and magnetic evidence.

At the beginning of this survey it was not certain what kind of anomalies would be associated with the dike and rift zones on Maui. The question, then, is whether or not the observed anomaly is indeed associated with a dike or rift zone. It was felt that a a simple model study which simulated the anomaly was needed to provide some substantiation.

Previous work by Malahaoff and Woollard (1965) demonstrated that the dike zones may be essentially vertical. But are the dike zones of large vertical extent in this area? To answer this question the gravity map was continued upward 700 feet (Fig. 16) to see if the anomaly was still present. (Henderson, 1960). A shallow, line source would be greatly reduced in amplitude, but a tabular body of some vertical extent would still be apparent. Although high frequency signals have been suppressed, the anomaly is still substantially present on the map, indicating that it has some vertical extent. Upward continuation to 3500 feet, reduced the amplitude of the anomaly and emphasized the regional contours. Note that Figure 16 is machine-contoured and that we can expect to see some additional smoothing (see discussion on contouring in Part II).

Prior to modelling, gravity profiles were obtained across the anomaly. Figure 17 shows the original anomaly and its residual after a gradient of .001 mgal/ft has been removed. The anomaly is only 0.6 mgal in amplitude along line B-B′ on the original map (Fig. 4). After upward continuation has been applied (and high frequency noise from near surface sources has been removed), the anomaly along lines C-C′ and D-D′ have amplitudes of 1.2 and 0.7 mgals respectively.

A simple two-dimensional gravity model was computed using the Talwani and others algorithm (1959). A dike dipping 30 degrees east was chosen to simulate the steeper gradient observed on the west half of the field anomalies (Fig. 17). The model dike was 1000 feet wide, 2500 feet long with its top 500 feet below the surface. The body density was chosen as 2.45 gm/cc; the country rock as 2.35 gm/cc. The model anomaly (Fig. 18) has a half maximum width of 3500 feet and an amplitude of 0.6 mgals. This compares reasonably with the observed anomalies, and suggests that a dipping dike may be a reasonable, if not unique, interpretation.

There were 6 magnetic profiles obtained originally in the Paia-Haiku area (all on file with the Geothermal Section). Of these, only two were considered meaningful to this study and they were combined into Profile E-E′-E′′-E′′′ (Fig. 9). The strong high frequency oscillations makes it difficult to interpret the magnetic profiles without some filtering. The red line on Figure 9 is sketched in by eye to help identify anomolous zones.

The letter A locates the center of the magnetic anomaly that is coincident with the gravity anomaly. It has an amplitude of approximately one-thousand gammas over a wavelength of 2.5 miles. An aeromagnetic profile has been included on Figure 9 for comparison; the coincidence of the two surveys gives further credence to the validity of the anomaly (if not the interpretation).

Anomaly B is not related to any observed gravity anomaly; but it is of significant size and possibly merits additional field investigation.

HANA.- Because there are only 29 stations in the Hana area (Fig. 8), the gravity contours are difficult to interpret. Nevertheless, there is a broad, positive anomaly of approximately 3-milligals centered where the East Rift zone is expected to occur (Fig. 1). There is no data to suggest that the anomaly has linearity similar to that observed in the Paia-Haiku area. Neverthess, the contours presented in this report are the first evidence to suggest that the rift is associated with a positive Bouguer anomaly in the Hana area.

A second feature of possible interest is a small gravity high trending northwest from the east rift zone anomaly. Red lines on Figure 8 delineate this secondary trend, but the location must be considered highly speculative at this time.

A gravity profile (Fig. 19) was constructed parallel to the coast. There is insufficient data on the profile to estimate the regional gradient from either trend surface techniques or upward continuation of the field. Without prior know;ledge of the gradients it is difficult to isolate either anomaly or to assign them a a given amplitude. Nevertheless, a gradient was sketched in by eye (dashed line) and as an estimate, the anomaly appears to be about 2 milligals; this is clearly a larger feature than the one-milligal anomaly observed in the Paia-Haiku area. The gravity profile barely shows the northwest trending anomaly; it is separated from the East Rift zone anomaly by a small notch in the profile.

Although the aeromagnetic profile does not show any anomaly in the Hana area, the ground surveys run in this study do show wide variations in amplitude (Fig. 12). The problem, as before, is to separate the anomolous features with structural significance from the noise arising from near-surface, shallow magnetic features of little interest to this report. A red line, again sketched by eye, helps to locate the anomolous zones.

The Hana area is marked by large magnetic changes, up to several thousand gammas. There are so many anomolous zones that selecting specific anomolies of interest is difficult. Therefore, I have selected arbitrarily those anomalies of exceptional amplitude or distinctive gradients. These are indicated by arrows on Figure 12 and by circles on the map (Fig. 8). No obvious trends are apparent, but the four anomolous zones selected happen to border the gravity anomalies. The steep gradients and short wavelengths indicate that the anomalies originate from local intrusive bodies of shallow depth and extent. Model studies are needed to further identify the sources.

MAKENA.- The Bouguer gravity map of Makena (Fig. 7) displays several sizeable anomalies of interest. There is a suggestion of a minor gravity low along the trend of the Southwest Rift zone (Fig. 1). Near the coast, there is superposed on this low a gentle positive-negative oscillation; Figure 19 displays these oscillations on the southeast edge of profile H-H′. Although the rift zones in Paia-Haiku and Hana have been characterized in this reprt as positive Bouguer anomalies, it is possible that the nature of the intrusives along the Southwest Rift in Makena are less dense than the country rock. The positive-negative variations may represent local intrusives of varying densities.

The Makena area is also characterized by a major positive anomaly trending northward (marked by a series of positive signs and delineated by parallel red lines on the Bouguer map). This sizeable feature is approximately five milligals in amplitude and varies from a width of several miles on the north to less than a mile near the coast. The profile (Fig. 19) displays this positive anomaly clearly.

Four magnetic profiles in the Makena area are located on the Bouguer map by the letters A-A′, B-B′, C-C′, and D-D′ and presented as plots on Figure 11. The plots again display the oscillations of several thousand gammas that characterize the Paia-Haiku and Hana areas. Certain anomalies were arbitrarily selected on the basis of gradient and amplitude and are again marked with arrows on the profiles and by circles on the map. The anomalies are not distributed in a meaningful areal pattern and are attributed to local intrusions of shallow depth and extent. Of course, modelling may reveal additional information about these features.

An extremely long profile (A-A′) was obtained across the surveyed area. The average value has been sketched in by eye (Fig. 11) and reveals a negative thousand gamma anomaly approximately seven miles in wavelength. The center of this anomaly is marked by the letter X on both the profile and map. The anomaly is similar to the negative anomaly observed in the Paia-Haiku area and suggested in this report as a possible characteristic of the Nortwest Rift.

The position of this north-trending gravity anomaly is sketched on Figure 15 for comparative purposes. The obvious disparity in directions between the Southwest Rift and this positive gravity feature indicates that it is some satellite feature; however, the large size of the anomaly (five milligals) must be taken into account in future modelling.

LAHAINA.- The statewide terrain-corrected Bouguer gravity contours (Fig. 3) form an ellipse elongate in the northwest-southeast direction. Although not well defined, the rift zones are presumed to follow this same trend (Fig. 1). Dike zones, recognized from surface features, lie along a northeast-southwest zone.

The Bouguer gravity contours in the Lahaina area (Fig. 5) is characterized by a westerly-trending low. There is not sufficient coverage to exactly delineate this feature, but upward continuation 670 feet (Fig. 20) helps localize the low. An approximation of the boundaries is made by the parallel (red) lines on Figures 5 an 20. A profile across the entire area (A-A′ on Fig. 21) shows the above low superposed on an estimate of the regional trend. The anomaly appears to have an amplitude of 3-milligals assuming the regional gradient is approximated correctly. A 3-milligal positive anomaly is also revealed on the southern edge of the profile.

A second profile was obtained parallel and close to the coastline. The profile shows alternating positive and negative anomalies. The presence of dike swarms in the area suggests that these alternating highs and lows are related to the dikes. However, the Bouguer contours (Fig. 5) are based on data that are so limited in areal coverage that these dikes do not show up as linear features. It is possible they are simply isolated intrusives. Certainly the strong newgative anomaly on the northwest edge of profile B-B′ appears to be a localized feature.

Of the six magnetic profiles obtained in the Lahaina area, four are of some interest to this study. Profile D-D′ (Fig. 10) encircled a known volcanic feature and revealed an anomaly with a distinctive low frequency oscillation; for the present such low frequency oscillations are considered to represent a magnetic signature for intrusives. I have, therefore, underlined similar low frequency signals on Figure 20. and placed circles on the map at the corresponding locations (Fig. 5).

OLOWALU.- The Olowalu area,a southward extension of the Lahaina area, is characterized by an extensive dike system (Fig. 1). The statewide gravity contours (Fig. 3) define a broad, positive anomaly but this is not clearly seen on the Olowalu Bouguer map (Fig. 6). A map continued upward 670 feet (Fig. 20), however, does display this positive anomaly as north-trending feature. (indicated by the parallel red lines). A projection of the anomaly northward is in the direction of one of the volcanic centers postulated by Malahoff and Woollard (Fig. 15).

The gravity contours (Fig. 6) also display positive-negative oscillations that may be attributed to the dike swarms of the area. There are two linear features that have enough extent to be of interest; a north trending positive anomaly (labelled A) and a northeast trending negative anomaly (labnelled B). The Bouguer gravity profile (Fig. 21) displays these anomalies, although the exact amplitude is uncertain without more extensive control. It is possible that a trend surface analysis may be useful, but it is not pssoble with such limited data.

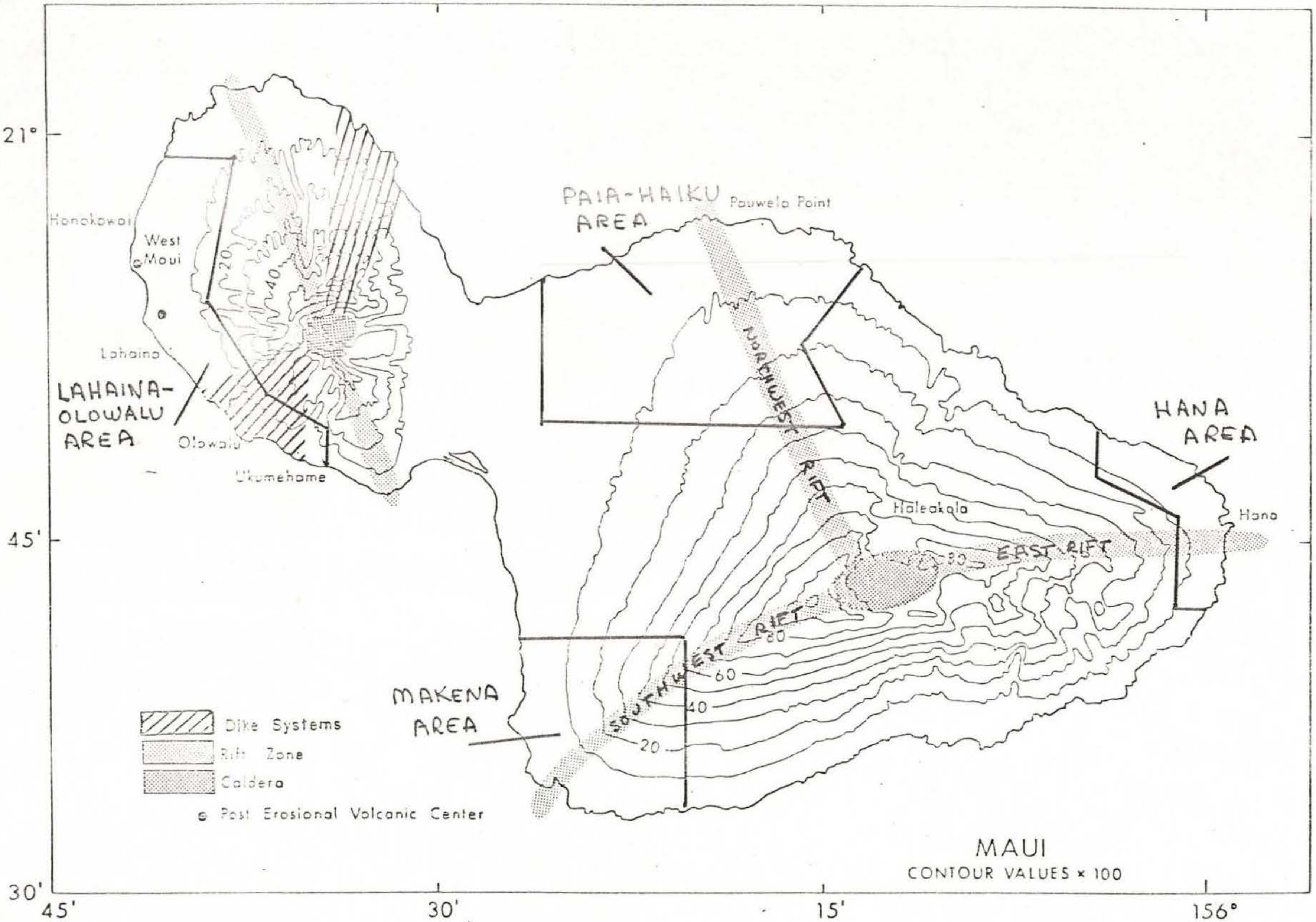


Figure 1. Index map showing areas of gravity and magnetic surveys, topography and rift systems of Maui (after Thomas and others, 1979).

Note to Draftsman: Original may be with Geothermal Section.

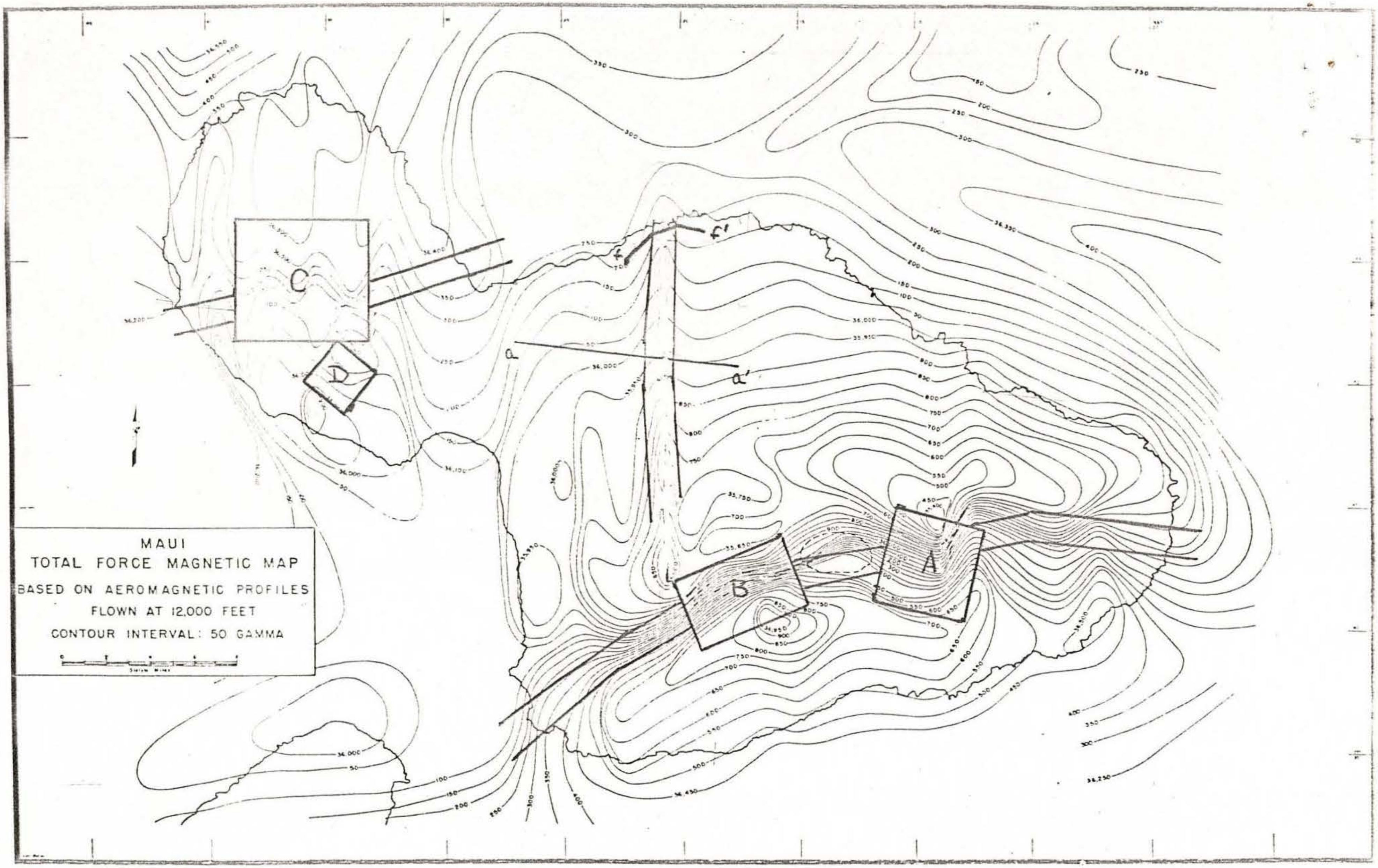


Figure 2. Total force magnetic map of Maui (from Malahoff and Woollard,1965). Capital letters identify magnetic structures (see Table 2). Lower case letters identify profiles. Parallel red lines locates possible dike or rift zone.

Kinoshita and Okamura,1965. Terrain corrected.
Woollard, unpublished. Not corrected for terrain.

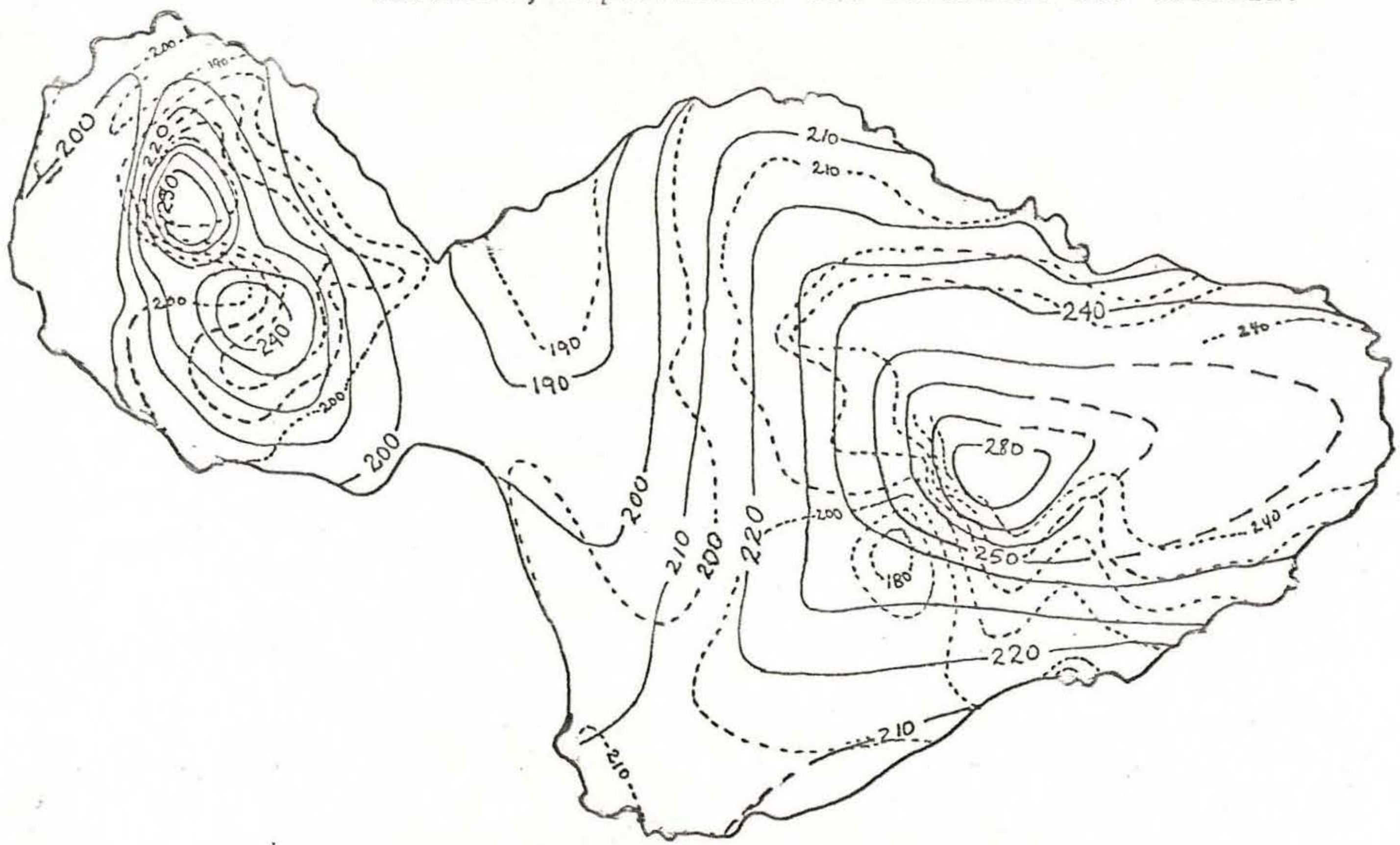


Figure 3. Comparison of Bouguer contours corrected for terrain (solid lines) with uncorrected contours (dashed lines).

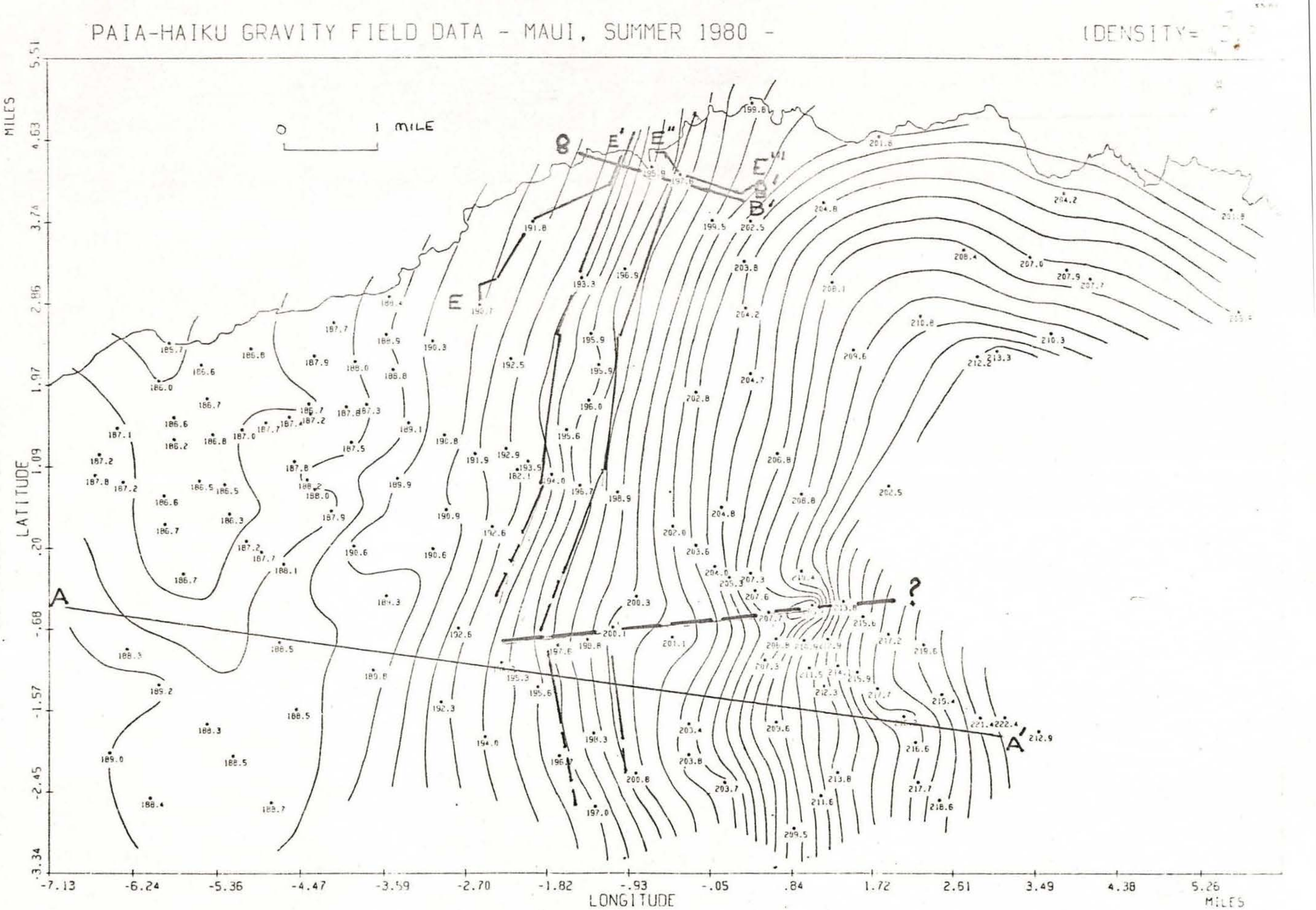


Figure 4. Bouguer gravity map of Paia-Haiku area. Contour interval one milligal. Letters identify gravity and magnetic profiles. Red lines identify possible rift zones. Dashed line identified possible fault zone.

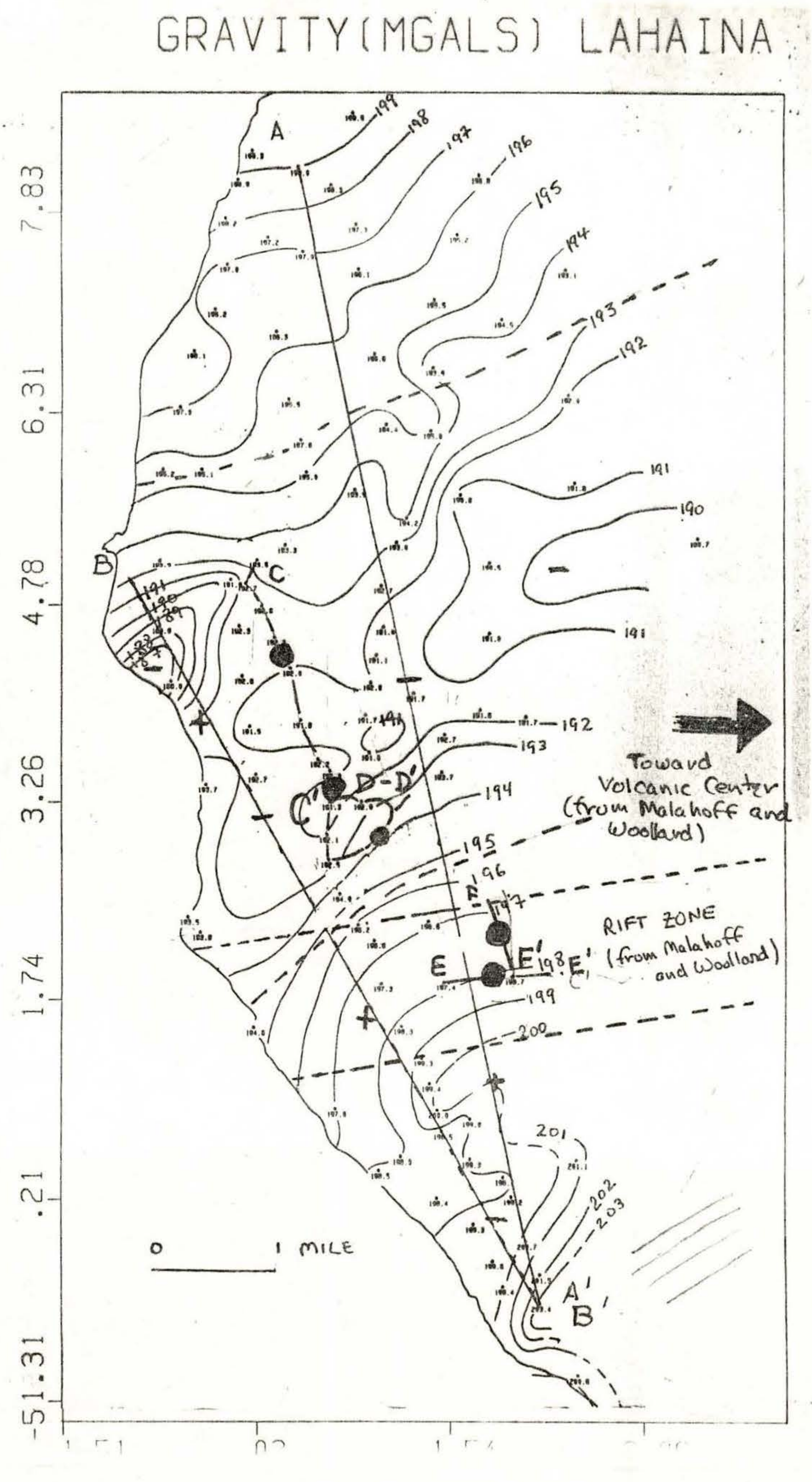


Figure 5. Bouguer gravity map of Lahaina area. Contour interval one milligal. Letters identify gravity and magnetic profiles

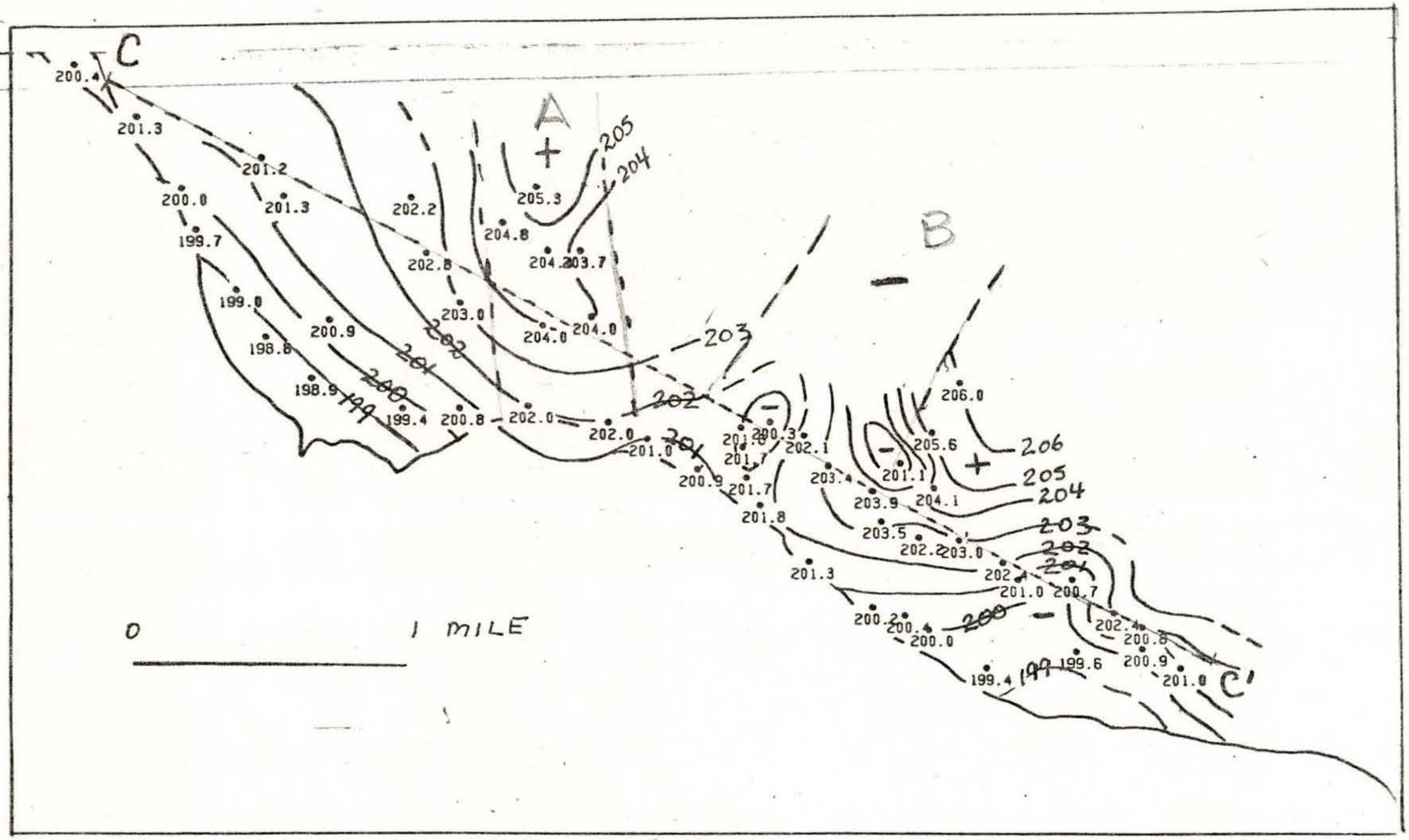


Figure 6. Bouguer gravity map of Olowalu area. Contour interval one milligal. Letters identify gravity and magnetic profiles.

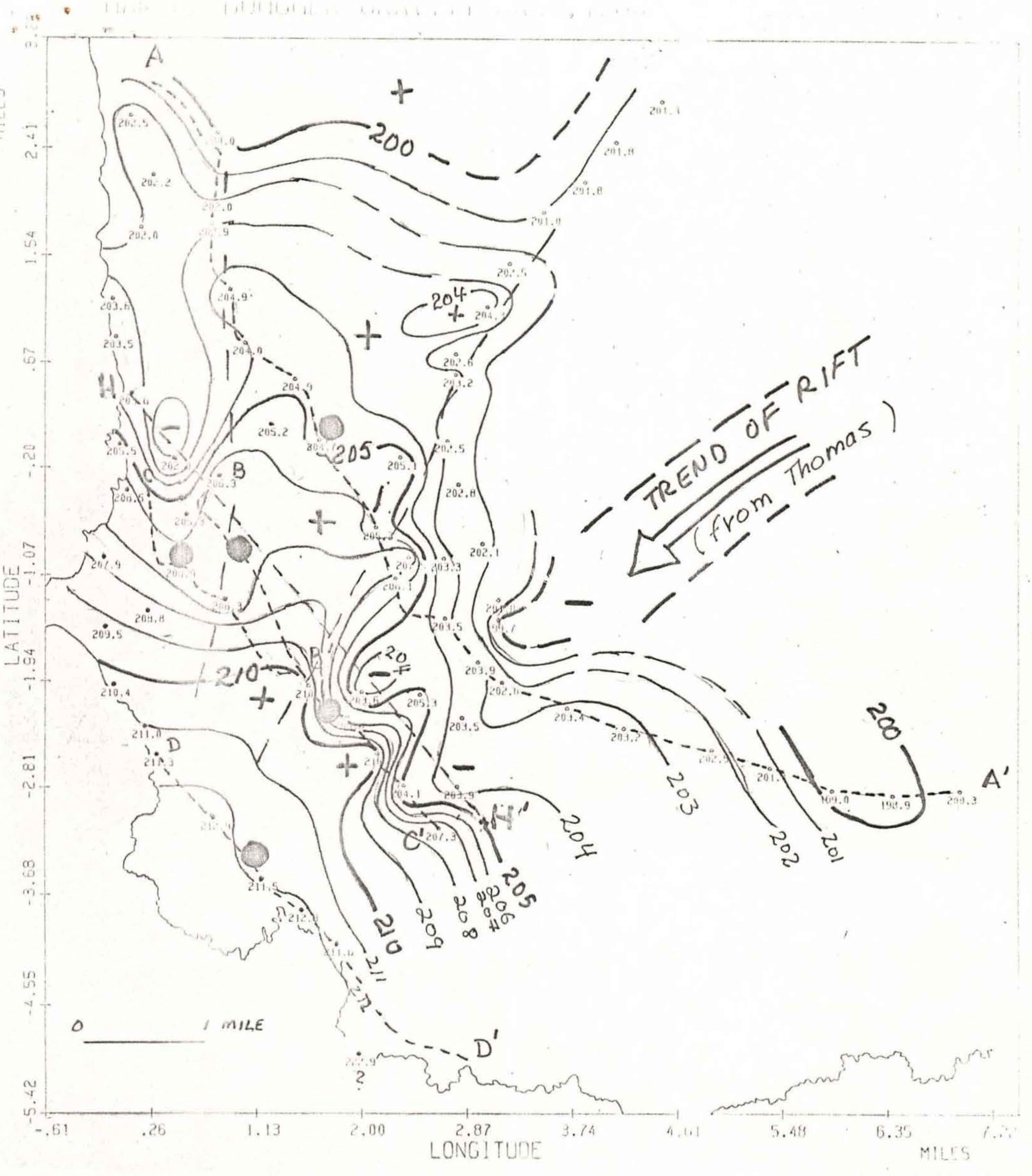


Figure 7. Bouguer gravity map of the Makena area. Contour interval is one milligal. Letters identify gravity and magnetic profiles.

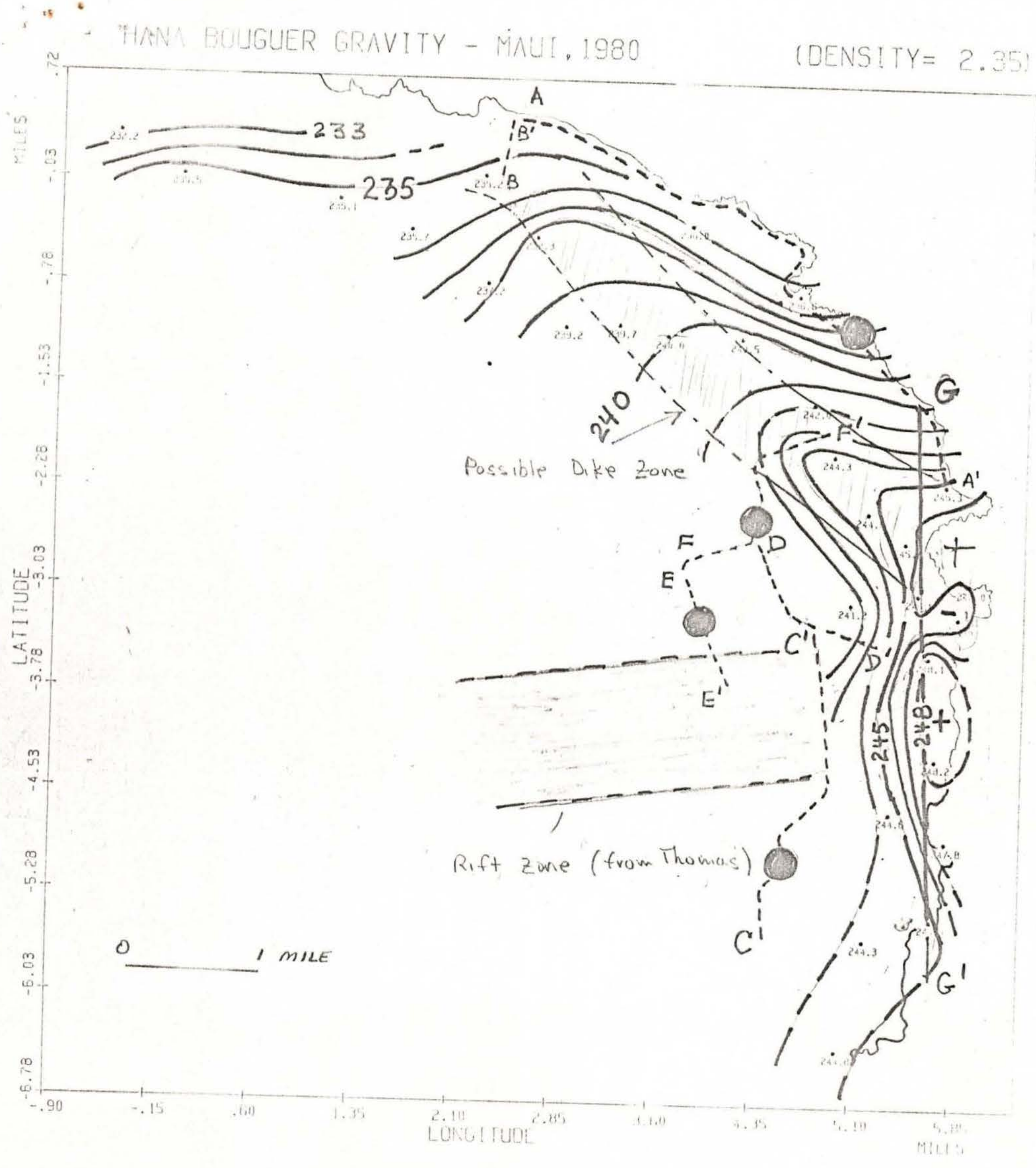


Figure 8. Bouguer gravity map of the Hana area. Contour interval is one milligal. Letters identify gravity and magnetic profiles.

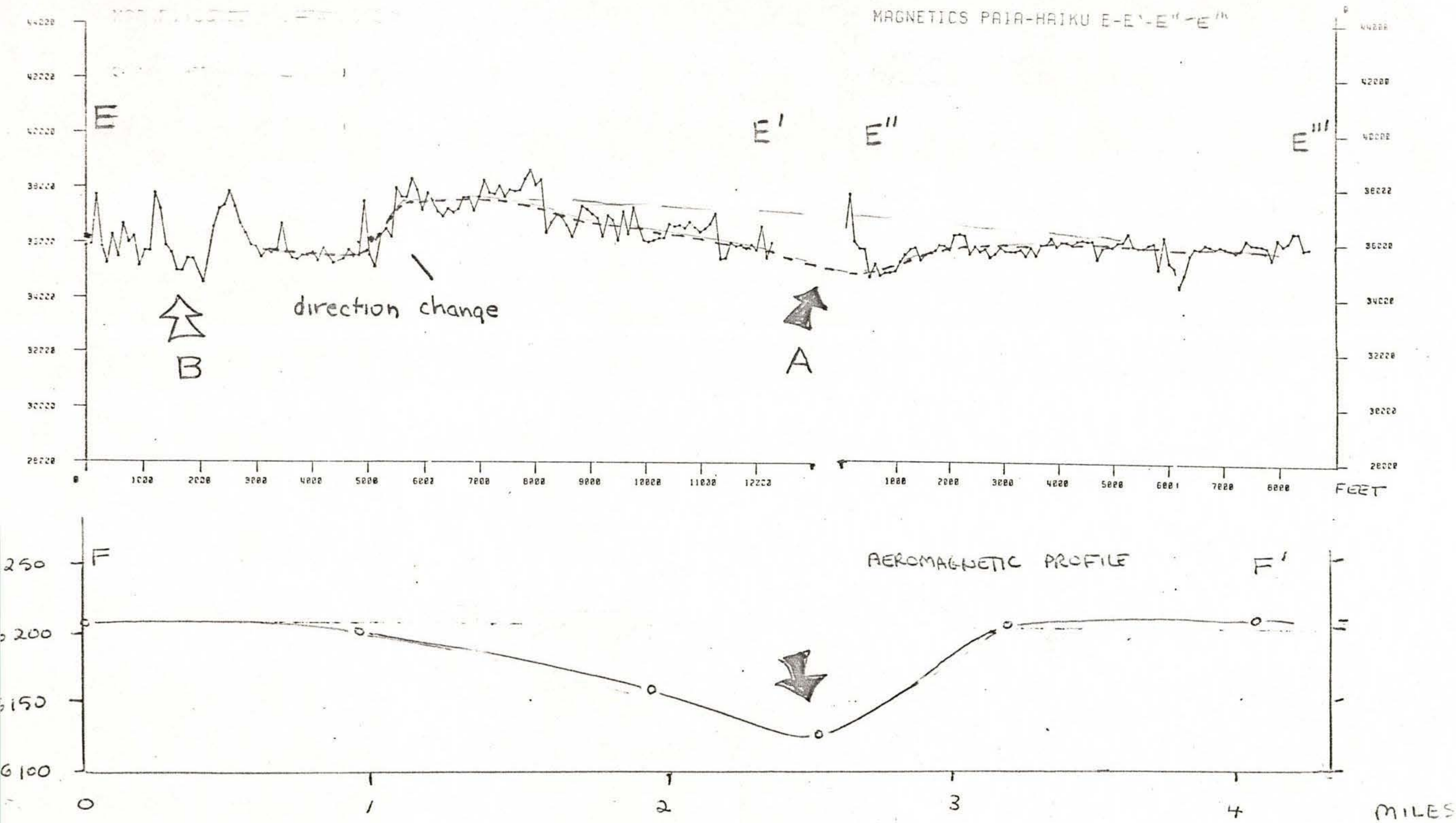


Figure 9. Ground and aeromagnetic total field profiles in Paia-Haiku area. See Figures 2 and 4.

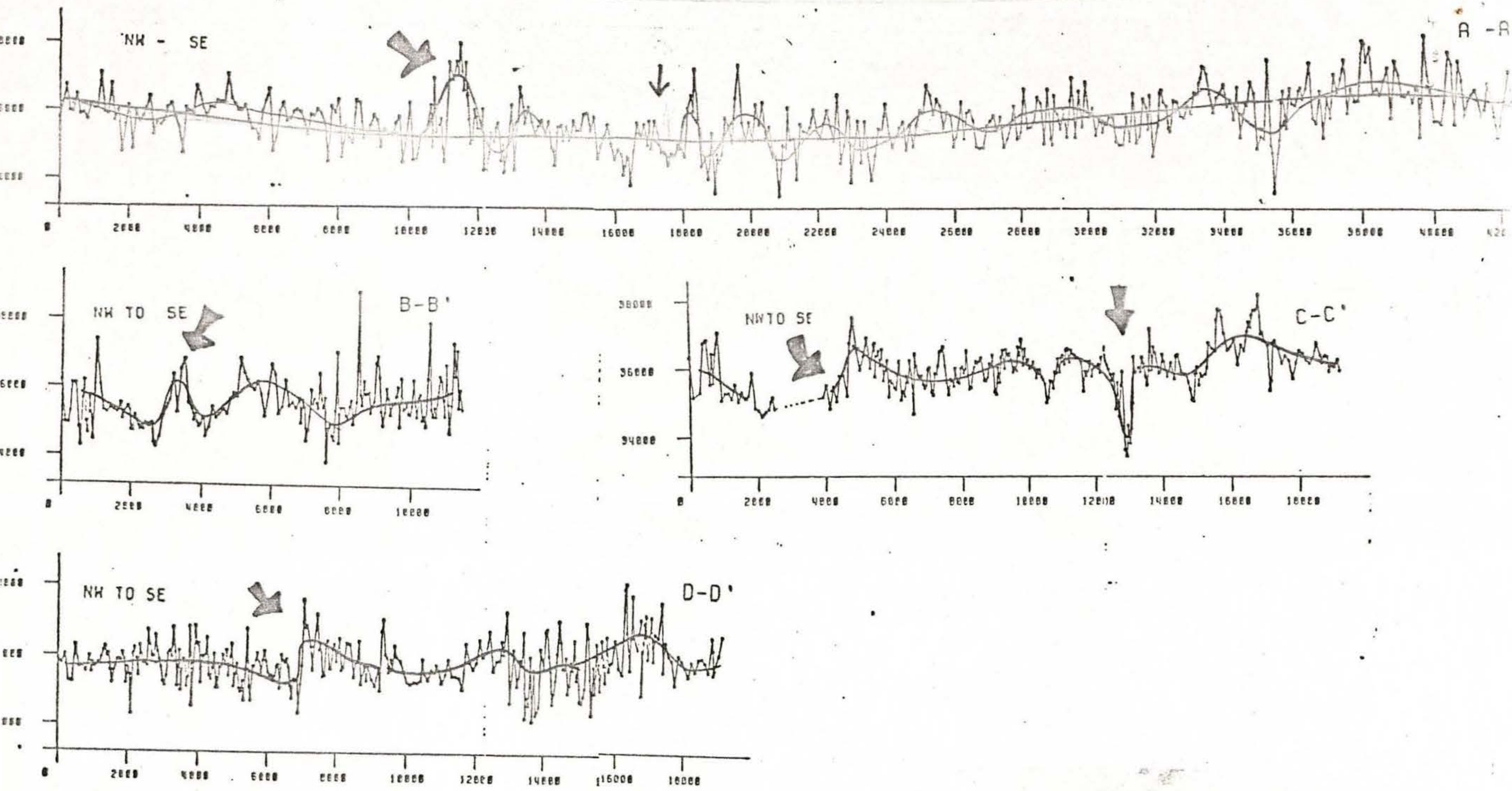


Figure 11. Total magnetic field profiles in the Makena area. See Figure 7.

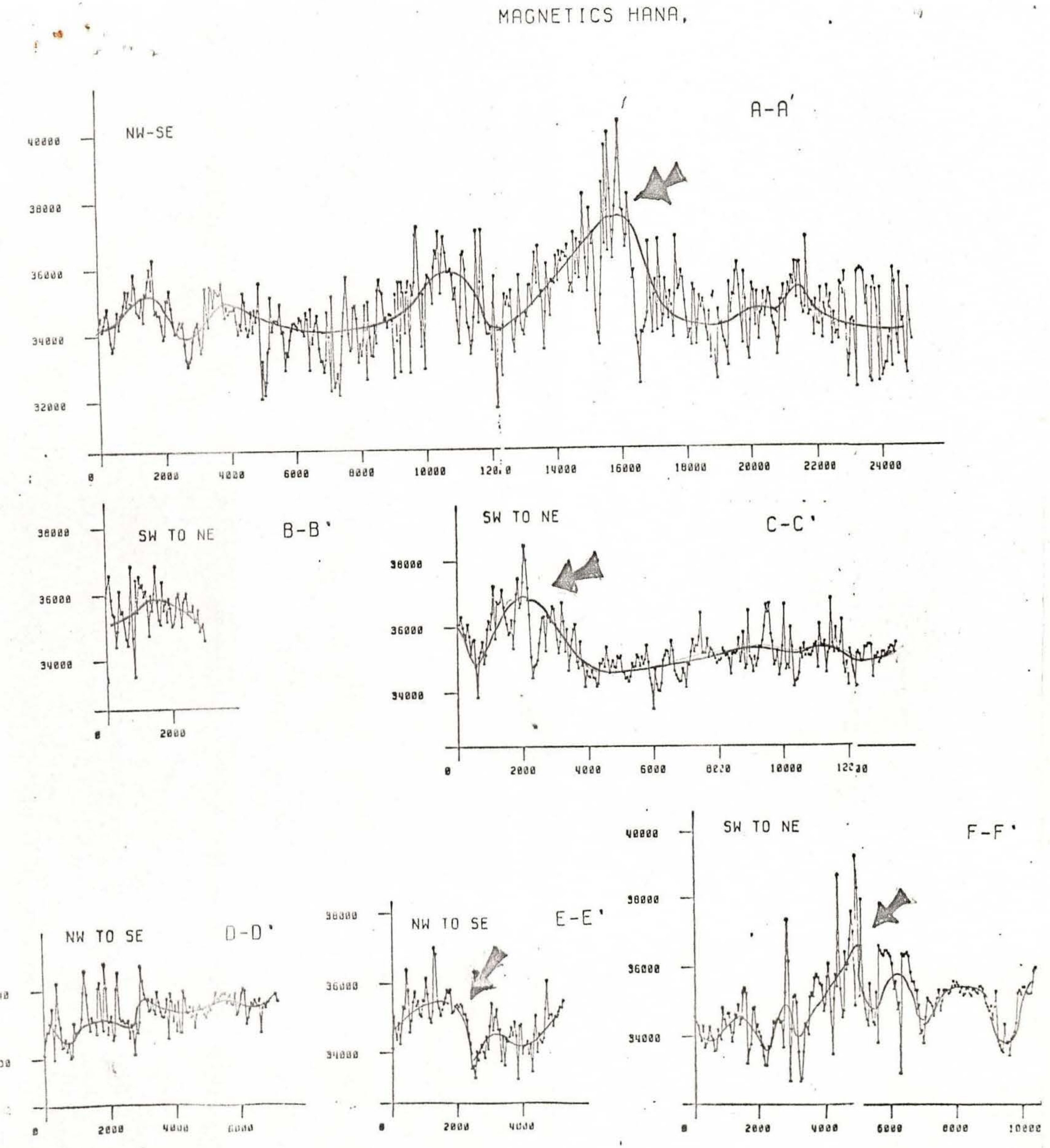


Figure 12. Total magnetic field profiles in the Hana area. See Figure 8.

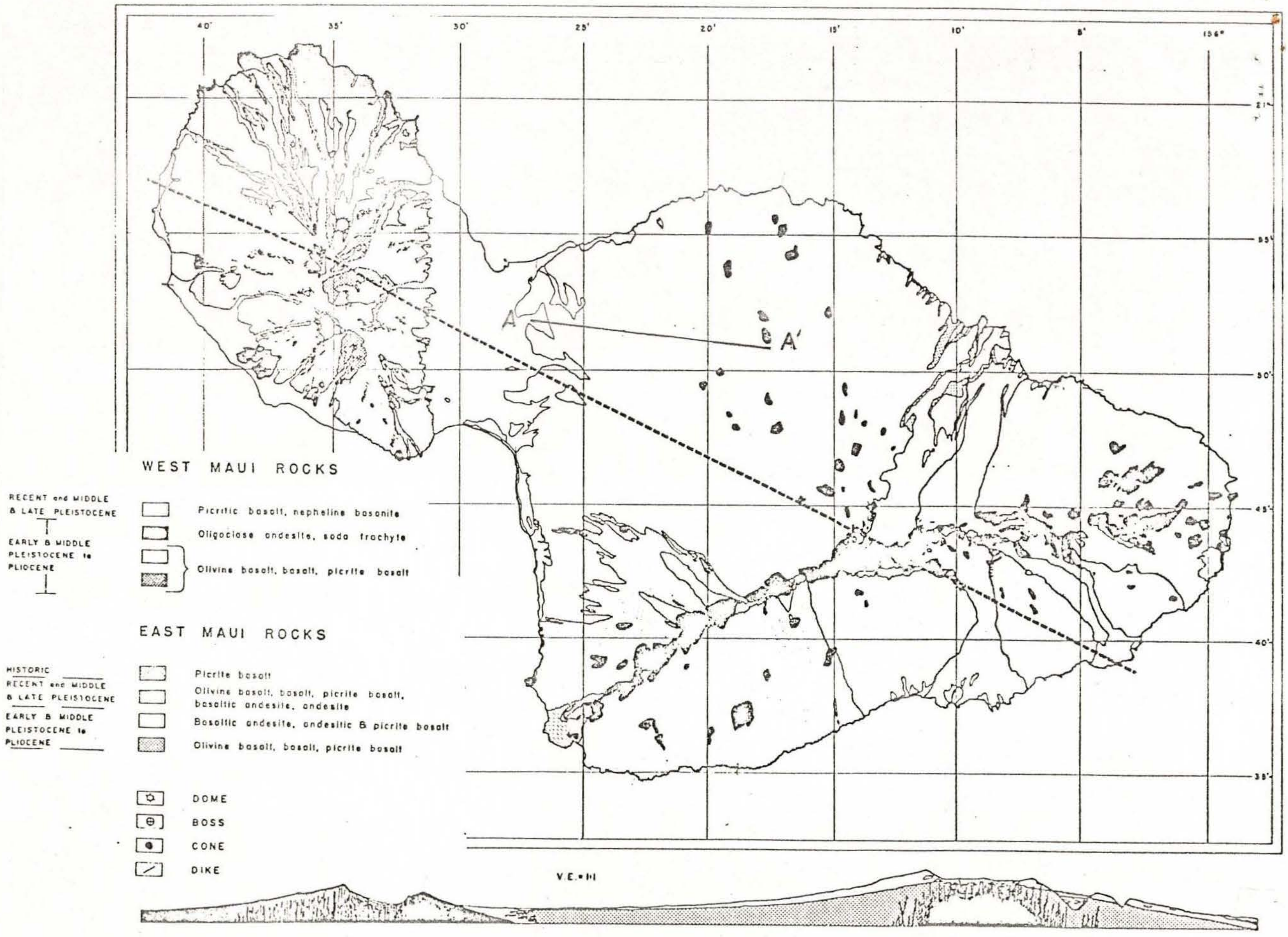


Figure 13. Surface geology of Maui. See Figures 2 and 4 for location of A-A' (From Thomas and others, 1979)

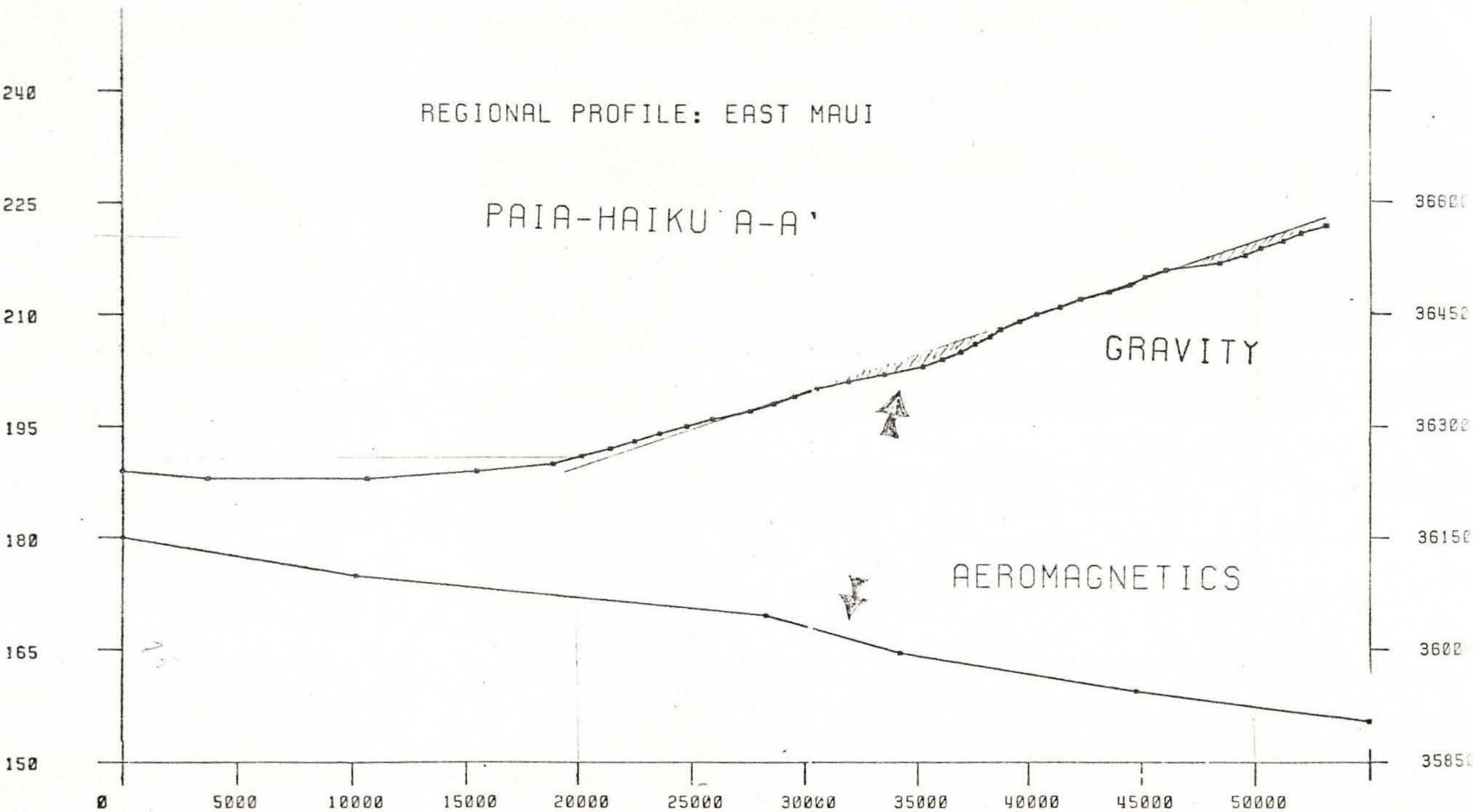


Figure 14. Gravity and aeromagnetic profiles in Paia-Haiku area. See Figures 2 and 4. Arrows identify anomalies of interest.

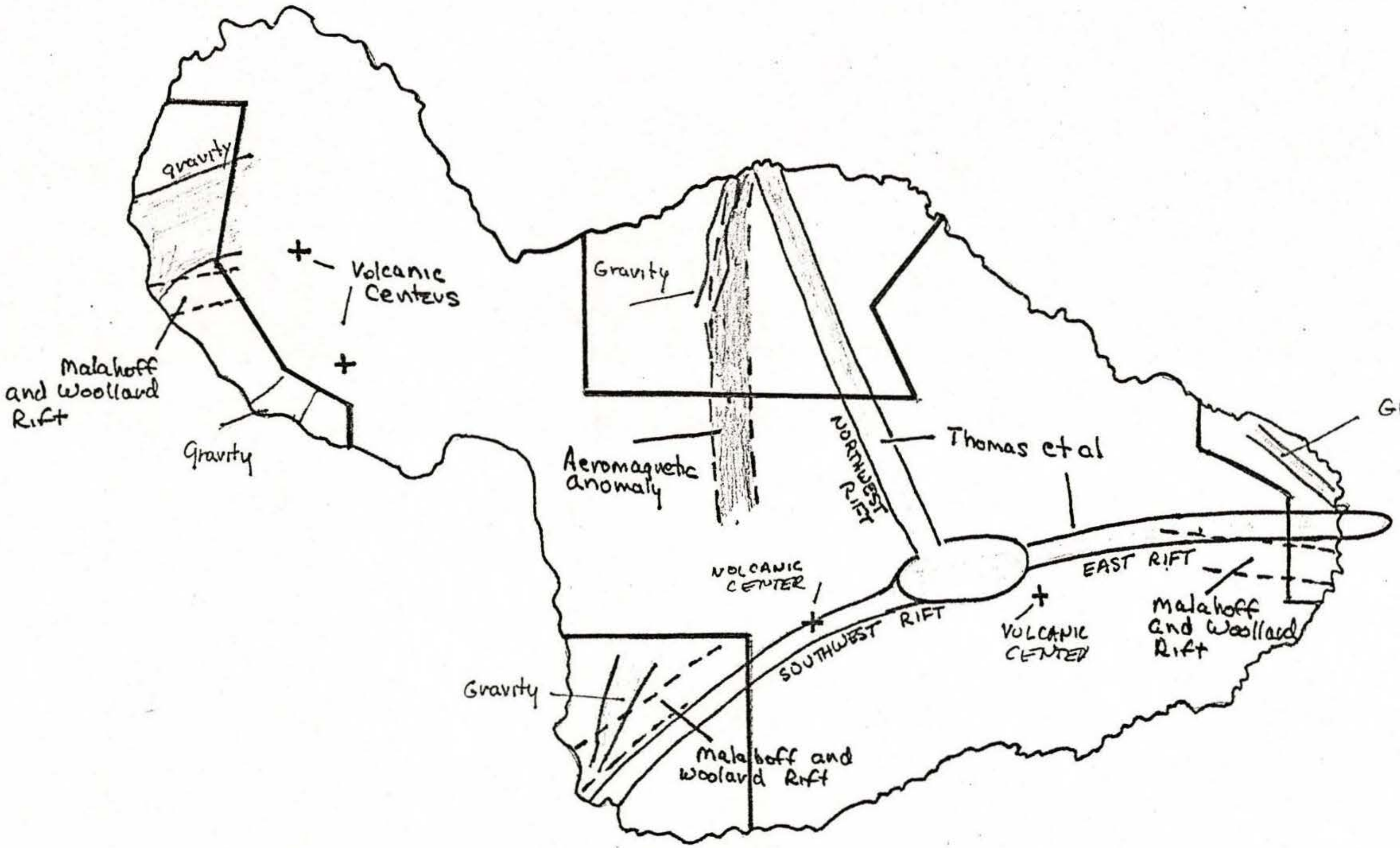


Figure 15. Sketch of Maui showing surveyed areas and anomolous zones discovered in this report.

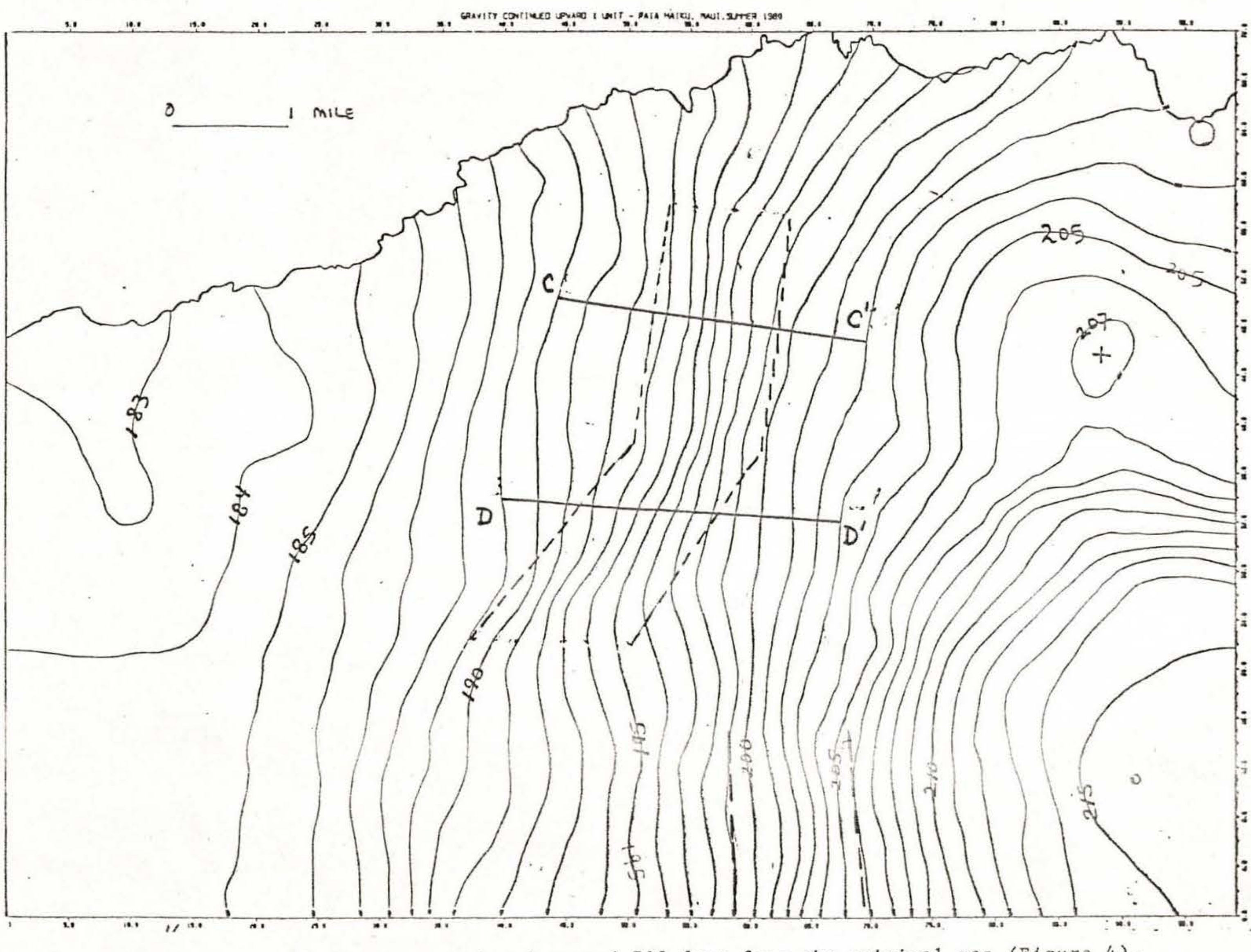


Figure 16. Bouguer gravity map continued upward 700 feet from the original map (Figure 4). Dashed lines outline linear anomaly trend. Letters identify profiles (Fig. 17).

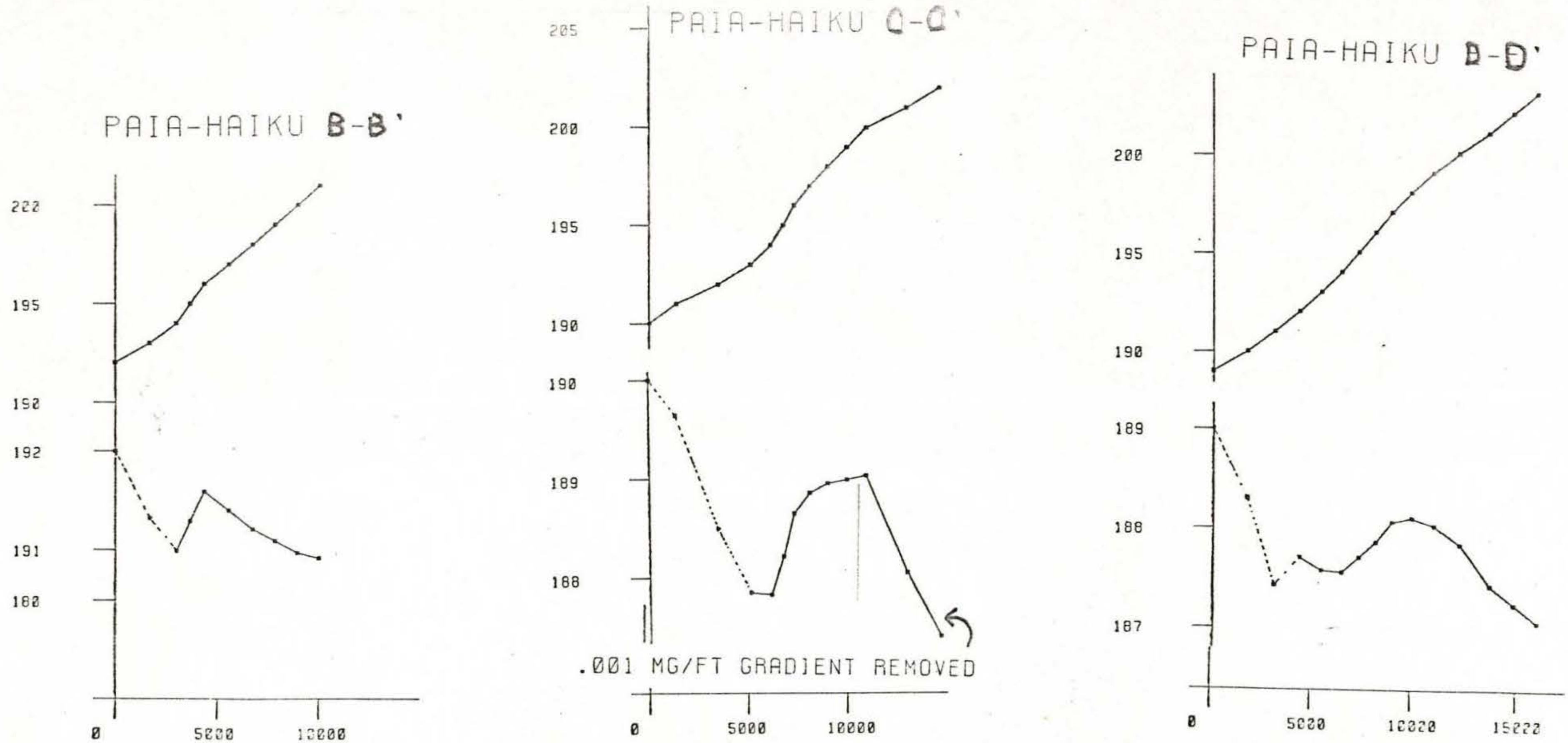
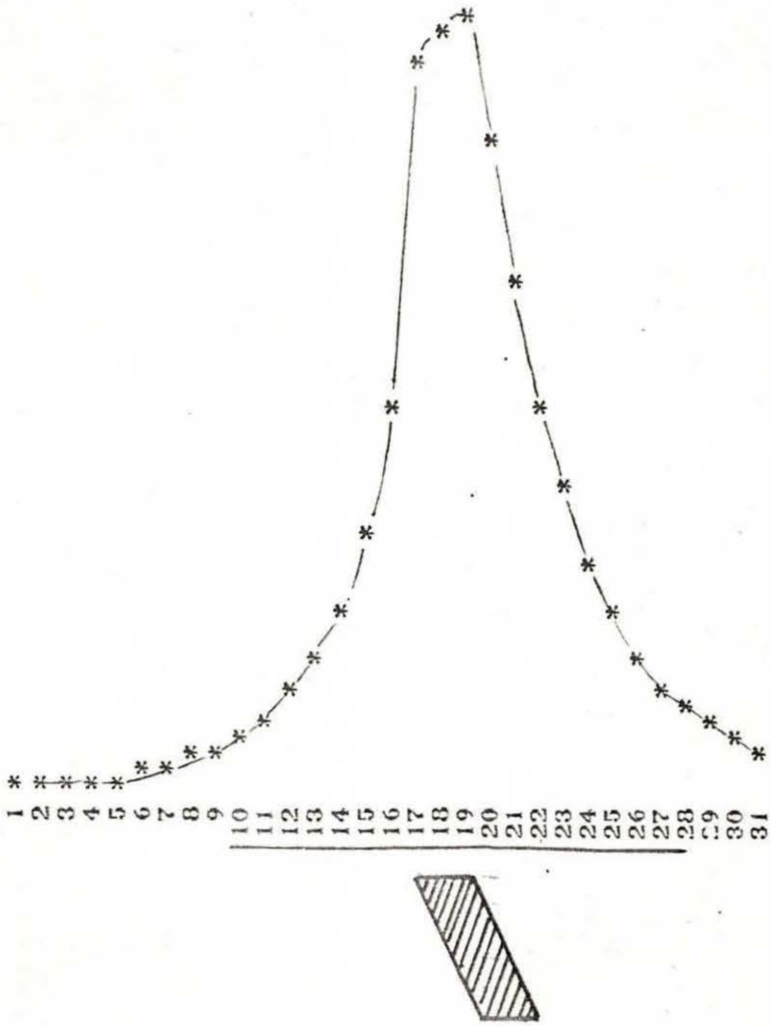


Figure 17. Bouguer gravity profiles from the Paia-Haiku area. Upper curves are original anomalies; lower curves have had .001 mgal/ft gradient removed. Vertical scale in mgals; horizontal scale in feet. Locations of profiles shown on Figures 4 and 16.

DIPPING DIKE. 1000 FT WIDE. 2500 FEET LONG. 30 DEGREE DIP.
COUNTRY ROCK DENSITY= 2.35
BODY DENSITY= 2.45

MIN(MGAL)= 0.020
MAX(MGAL)= 0.632
SCALE(MGAL/INCH)= 8.159



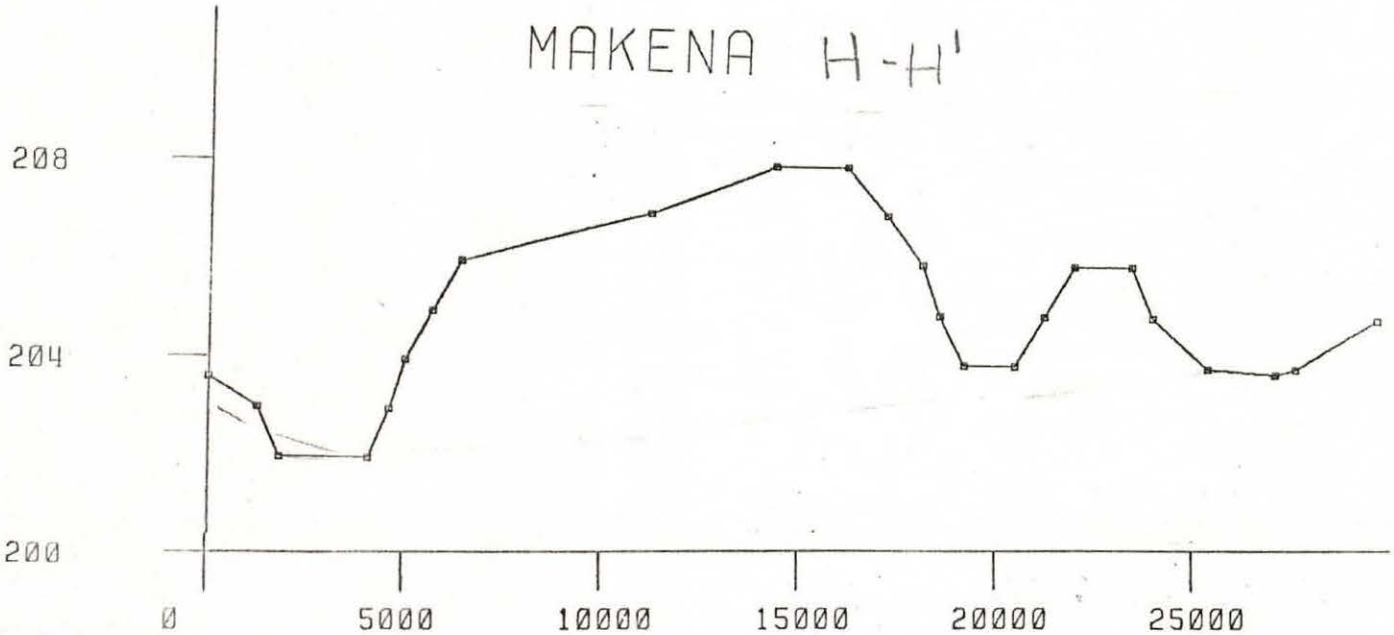
COORDINATES OF BODY VERTICES

	X	Z
1	8000.00	500.00
2	9000.00	500.00
3	10443.00	3000.00
4	9433.00	3000.00

GRAVITY FIELD

STA	DISTANCE	ELEVATION	MILLIGALS
1	0.00	0.00	0.02
2	500.00	0.00	0.02
3	1000.00	0.00	0.02
4	1500.00	0.00	0.03
5	2000.00	0.00	0.03
6	2500.00	0.00	0.04
7	3000.00	0.00	0.04
8	3500.00	0.00	0.05
9	4000.00	0.00	0.06
10	4500.00	0.00	0.07
11	5000.00	0.00	0.08
12	5500.00	0.00	0.10
13	6000.00	0.00	0.13
14	6500.00	0.00	0.16
15	7000.00	0.00	0.22
16	7500.00	0.00	0.32
17	8000.00	0.00	0.59
18	8500.00	0.00	0.62
19	9000.00	0.00	0.63
20	9500.00	0.00	0.53
21	10000.00	0.00	0.42
22	10500.00	0.00	0.33
23	11000.00	0.00	0.25
24	11500.00	0.00	0.20
25	12000.00	0.00	0.16
26	12500.00	0.00	0.13
27	13000.00	0.00	0.10
28	13500.00	0.00	0.08
29	14000.00	0.00	0.07
30	14500.00	0.00	0.06
31	15000.00	0.00	0.05

Figure 18. Gravity anomaly computed for a dipping dike model.



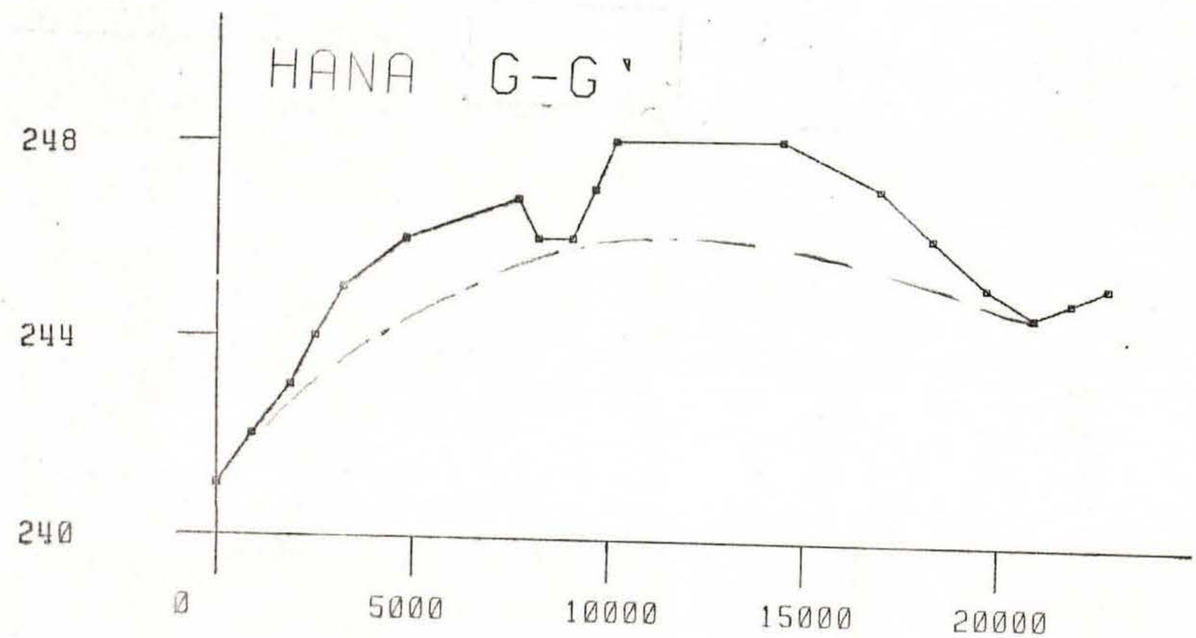


Figure 19. Gravity profiles in the Hana and Makena areas. Vertical scale in milligals; horizontal in feet.

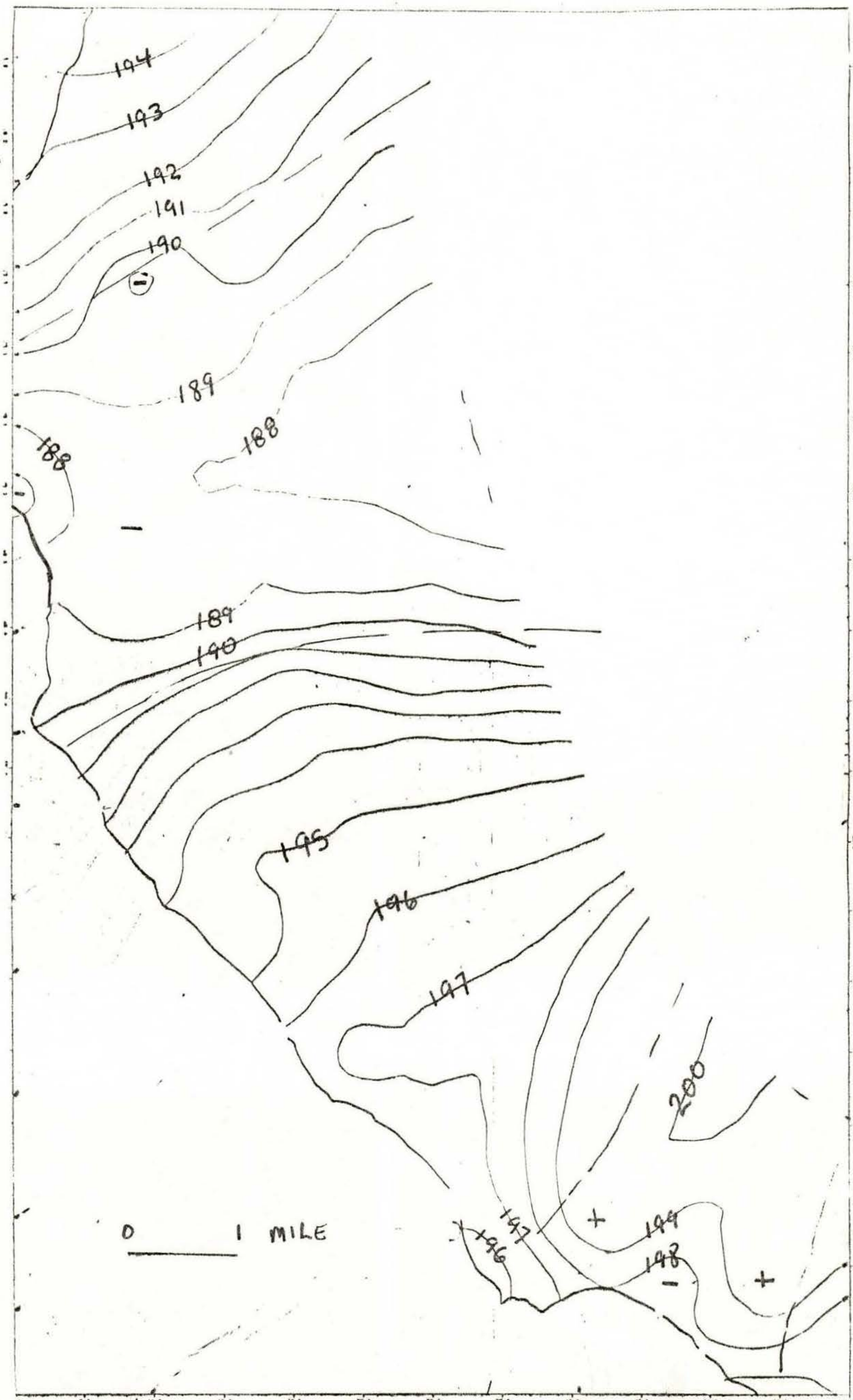


Figure 20. Bouguer gravity map continued upward 670 feet from the original map (Figure 5). I' hed lines outline gravity low.

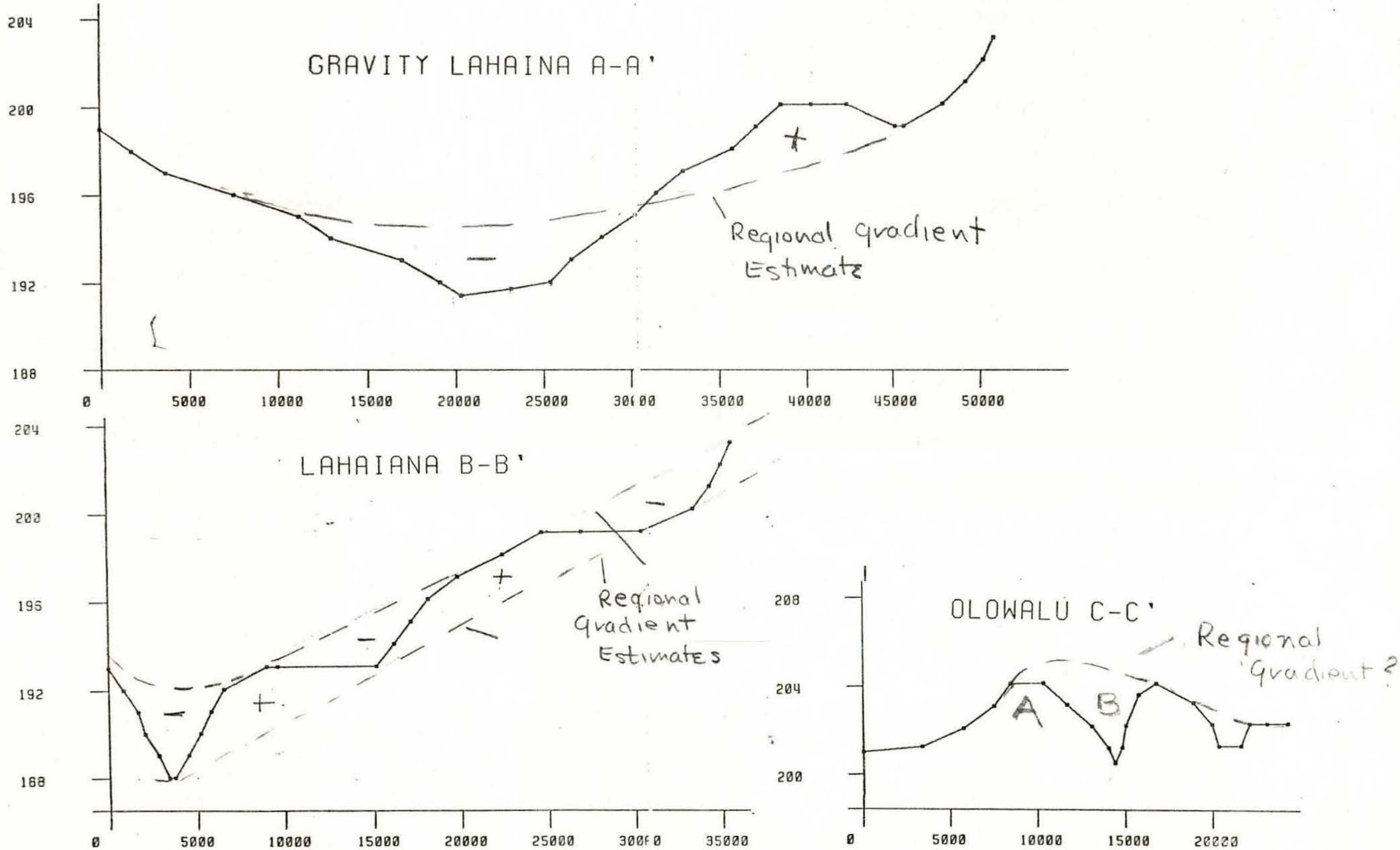


Figure 21. Bouguer gravity profiles from the Lahaina and Olowalu areas.

Table 1. Facsimile of gravity data input for computer data reduction. Data for all areas on file with the Geothermal Section.

```
MAGNETIC FIELD(GAMMAS) HANA,1980
GRAVITY(MGALS) HANA
LOCATION UNIT (MILES=1, ETC)          1
ELEVATION UNIT (FT=2,ETC)             2
TIME ZONE CORR TO GREENWICH           10
INST CONVERSION FACTOR (MG)           0.11428
RESET VALUE TO ADJUST GRAVITY         -2878.897
LATITUDE OF GRAND BASE STATION        +20.891
LONGITUDE OF GRAND BASE STATON        -156.076
DATUM ELEV FOR GRAV REDUCTION         0.0
FLAGS FOR GRAV OUTPUT: TIDE           1
                       LATITUDE       1
                       DRIFT          1
                       FREE AIR       1
                       GRAV PLOT      1
                       MAG PLOT       0
                       STA NOS        1
                       MAP DATA       1
                       NO DUPES       1
CACLOMP SCALE FACTOR                  2.1870
STATION HEIGHT IN INCHES ON PLOT      0.050
DATA HEIGHT IN INCHES ON PLOT         0.050
LOCATION SYMBOL HEIGHT IN INCHES      0.020
FLAG: NORTH-SOUTH IS PLOT LENGTH      1
TOTAL NUMBER OF READ-IN VALUES         40.
START OF OBSERVATION (YEAR)           1980
                     (MONTH)          08
                     (DAY)            09
                     (HOUR)           11
                     (MIN)            42
1980 8 91142   1B 27269.800   -3.000     5.550    98.000    0.000   36000.
        1218   2  27242.000   -2.410     5.170   123.000    0.000   35500.
        1248   3  27217.800   -1.980     4.910   166.000    0.000   36800.
```

DATE & TIME

STATION NOS

GRAVITY READING

MILES N/S AND E/W OF BASE

ELEVATION

INST. HEIGHT

MAGNETIC READING

```
        1245   2B 27245.900   -2.410     5.170   123.000    0.000   35500.
        1412   28 26996.100   -3.080     5.050   505.000    0.000   35000.
        1445   29 27217.300   -6.360     5.000   120.000    0.000   36000.
        1517   2B 27243.600   -2.410     5.170   123.000    0.000   36000.
DENSITY FOR BOUGUER CORRECTION     2.35
EOF..
```

Table 2. Analyses of aeromagnetic anomalies over Maui (from Malahoff and Woollard, 1965).

1*	2*	3*	4*
(A) East Haleakala Volcanic Pipe Zone	4.0	7.3 by 7.3	15 approx.
(B) West Haleakala Volcanic Pipe Zone	3.3	8.0 by 6.4	12
(C) West Maui Volcanic Pipe Zone	1.6	9.5 by 8.9	9
(D) West Maui Minor Volcanic Pipe Zone	0.5	4.0 by 4.0	3

1* Name of feature

2* Depth to top of anomalous body below ground level in kilometers

3* Approximate horizontal cross section of anomalous body in kilometers

4* Vertical length of anomalous body in kilometers

5* Magnetization contrasts between anomalous body and surrounding rock in cgs units